Zonal Jets in the Equatorial Atlantic Ocean

ZONAL JETS IN THE EQUATORIAL ATLANTIC OCEAN

by Miquel Rosell-Fieschi[(1)], Josep L. Pelegrí [(1)*], Jérôme Gourrion[(2)]

[(1)]: Departament d'Ocenografia Física i Tecnològica, Institu de Ciències del Mar, CSIC, Barcelona, Spain

[(2)]: CNRS, DT-INSU, Plouzané, France

* ***Corresponding author :*** Josep L. Pelegrí

<u>REFERENCE</u> : ROSELL-FIESCHI, M., J. L. PELEGRÍ AND J. GOURRION : « ZONAL JETS IN THE EQUATORIAL ATLANTIC OCEAN », PROGRESS IN OCEANOGRAPHY, VOL. 130, PP 1-18, 2015,
DOI: 10.1016/J.POCEAN.2014.08.008

INTRODUCTION

Argo floats data have been used to investigate the zonal jet structure of the flow field at the sea surface and on three subsurface layers (Central Waters, 200 m; Antarctic Intermediate Waters, 1000 m; upper North Atlantic Deep Waters, 1500 m) in the equatorial Atlantic Ocean system (15°S to 15°N). The surface currents are dominated by an annual cycle between 4°N and 10°N and, to a lesser degree, by a semi-annual contribution close to the equator. This variability is an outcome of evolving zonal recirculations and some regions as Inter-Tropical Convergence Zone (ITCZ) are involved. The major characteristics of the zonal jets in the equatorial Atlantic Ocean at surface and sub – surface levels are shown in Table 1.

Level	Current	Core latitude	Flow seasonal cycle (boreal seasons)
Sea surface	North Equatorial Countercurrent, NECC	5–8°N	East, with fall maximum up to 0.5 m s^{-1}
	Northern South Equatorial Current, nSEC	2–3°N	West, with summer-fall maximum up to 0.6 m s^{-1}
	Equatorial Under Current, EUC	0°	East at subsurface, surfaces in the western basin on summer reaching 0.3 m s^{-1}
	Central South Equatorial Current, cSEC	4°S	West with spring–summer maximum up to 0.4 m s^{-1}
1000 dbar	North Equatorial Intermediate Current, NEIC	3–4°N	West in spring, up to 0.07 m s^{-1}; east in fall, less than 0.05 m s^{-1}
	Equatorial Intermediate Current, EIC	0°	West in summer, up to 0.14 m s^{-1}; east in winter, up to 0.10 m s^{-1}
	South Equatorial Intermediate Current, SEIC	2–4°S	West in winter–spring, up to 0.07 m s^{-1}; east in summer-fall, up to 0.05 m s^{-1}
Sub-surface	Equatorial Deep Jet, EDJ	2°S to 2°N	Between 300 and 2500 m, alternate directions in vertical scales of 400–600 m, direction changes with season
	Extra-Equatorial Jets, EEJs	3°S and 3°N	From 200 m down to the sea floor

***TABLE** : MAJOR CHARACTERISTICS OF THE ZONAL JETS IN THE EQUATORIAL ATLANTIC OCEAN AT SURFACE AND SUB-SURFACE LEVELS*

The predominant surface current is the westward flowing Southern Equatorial Current (SEC). This current is composed of three branches: central (cSEC), equatorial (eSEC) and northern (nSEC). On the other hand, the North Equatorial Countercurrent (NECC) is characterized by an intense annual cycle and it is found between the sea surface and depths of about 350 m. Other major zonal currents are observed at subsurface levels, flowing east under the wind-driven westward SEC. These are the Equatorial Undercurrent (EUC), centered at the equator and 100 m depth, and the off-equatorial South/North Equatorial under Currents (SEUC/NEUC), centered at some 150 – 200 m and 4ºN/4ºS. Besides, Equatorial Deep Jets (EDJs) are found at depths between 300 and 2500 m. These jets have relatively short meridional scales, as little as only 1°, and display alternating directions on vertical distances of 400 – 600 m with velocities about 0,2 $m.s^{-1}$. Their vertical structure is quite consistent through one same season but changes with season.

DATA AND METHOD

Velocity fields at the surface and at several parking depths from Argo database was performed. Only the first and last surface transmissions were used to calculate the surface velocities, maximizing the surface distance and time. For the deep displacement we used the last position transmission before departure from the sea surface and the first position transmission after the next sea surfacing. As a result, one surface and one deep velocity vector per cycle were generated. Only three parking depths were chosen to generate the sub-surface velocity fields: Surface waters (all floats), central waters (floats at 200 dbar), intermediate waters (floats at 1000 dbar) and upper North Atlantic Deep Water (floats at 1500 dbar).

A 0.5° latitude-longitude resolution grid was used to assign all velocity vectors contained in an ellipse with a zonal major axis of 400 km and a meridional minor axis of 200 km to each grid cell. Drift due to tidal/inertial motions and time lags between the surfacing/sinking and first/last transmission times were calculated as deep-velocity error. We find that the most probable error is less than 3%, with 58% of the velocity estimates having a relative error less than 10%, and 93.7% of the velocity estimates having an absolute error smaller than de velocity value itself.

In order to assess the amplitude and phase of the annual and semi – annual periodicities, a classical harmonic analysis of the zonal component was carried out.

CONCLUSIONS

The data confirms the predominance of the zonal jets in the equatorial Atlantic at all level. At the sea surface, the jets intensify seasonally but do not change direction, except for the summer appearance of the NECC. At the AAIW level (Fig. 1), we find three jets that change direction throughout the year: one centered at the equator and two adjacent opposite currents.

Seasonal evolution of the flow both at the surface and AAIW levels was explored. The April intensification of the NECC starts in the eastern Atlantic through a northern diversion of the nSEC, which progressively extends westwards until August, following the latitudinal displacement of the ITCZ. At latitudes between 4ºN and 10ºN the forcing winds have both annual and semi-annual signals that are reflected in the surface zonal currents. Between 2ºS and 4ºN, the dominant atmospheric forcing is annual yet there is a major semi – annual response that arises from the latitudinal diversion of the flow, resulting in the seasonal appearance of the NECC.

At the AAIW level the major jets remain locked within less than 5° of latitude from the equator, with both annual and semi – annual contributions (Fig. 2). These seasonal anomalies reach values of about 0,1 $m.s^{-1}$, several times larger that the annually – averaged currents, being responsible for the observed flow inversions. Their zonal evolution is consistent with the speed of westward propagating planetary waves, at latitudes which define the location of the AAIW zonal jets (3ºS, 0º, 3ºN). The propagation is slow enough to be detected by our temporally – smoothed velocity data; this contrasts with the situation observed at the surface level, where any Rossby wave would propagate too fast to be captured by our monthly velocity fields.

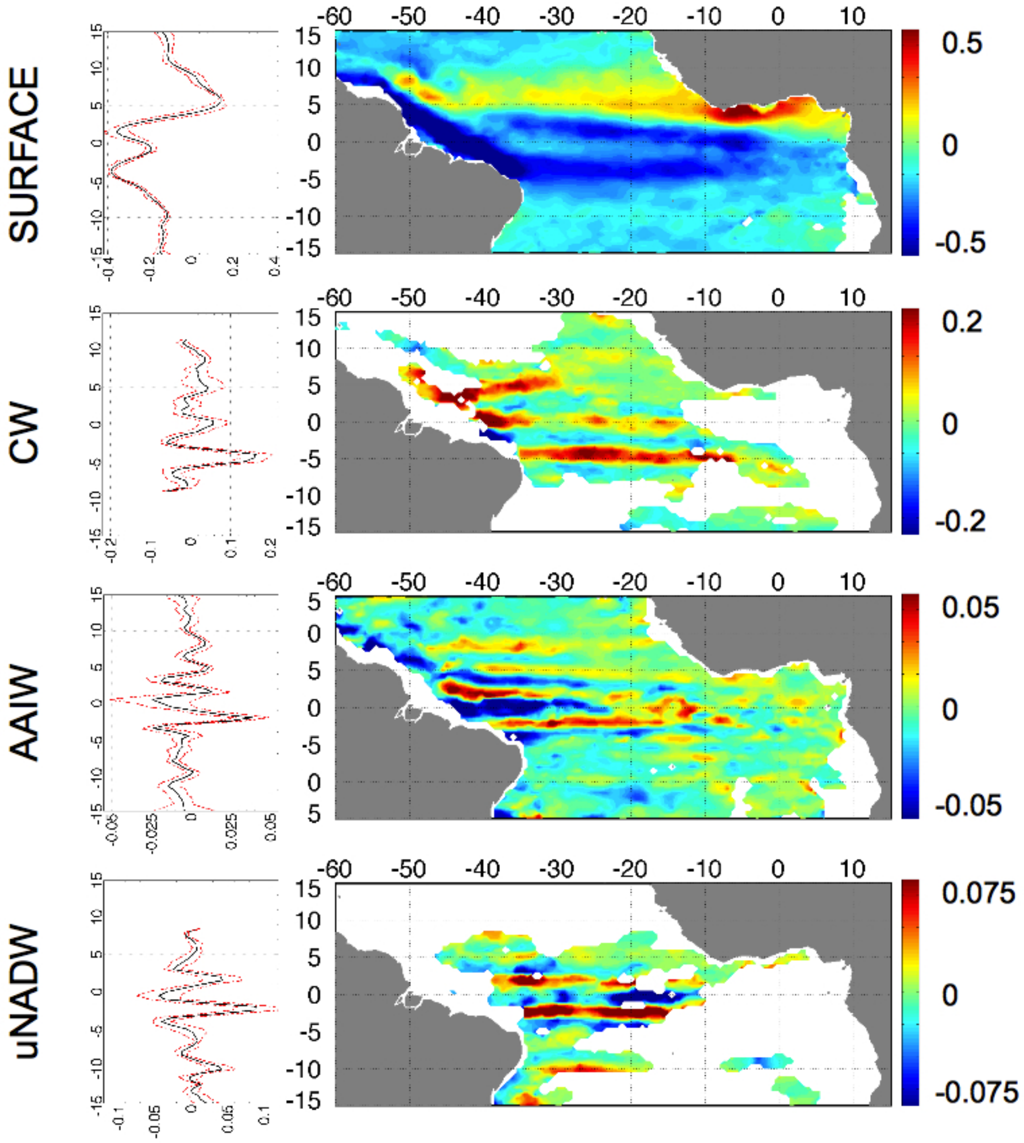

FIGURE 1 *- CONTOUR MAPS FOR THE ANNUAL-MEAN ZONAL VELOCITIES (MS-1) AT SURFACE (TOP), CW (SECOND ROW), AAIW (THIRD ROW) AND UNADW (BOTTOM) LEVELS. NOTE THE CHANGE IN SCALE BETWEEN THE LEFT AND RIGHT PANELS. EACH PANEL IS ACCOMPANIED BY A BOX THAT SHOWS THE LATITUDINAL DISTRIBUTION OF THE ZONALLY-AVERAGED (33ºW TO 20ºW) ZONAL VELOCITY AS A FUNCTION OF LATITUDE (BLACK LINE). THE DASHED RED LINES SHOW ONE STANDARD DEVIATION AS CALCULATED USING THE CELL-MEAN VALUES (0.5º LATITUDE GRID) BETWEEN 33ºW AND 20ºW. (FOR INTERPRETATION OF THE REFERENCES TO COLOUR IN THIS FIGURE LEGEND, THE READER IS REFERED TO THE WEB VERSION OF THIS ARTICLE)*

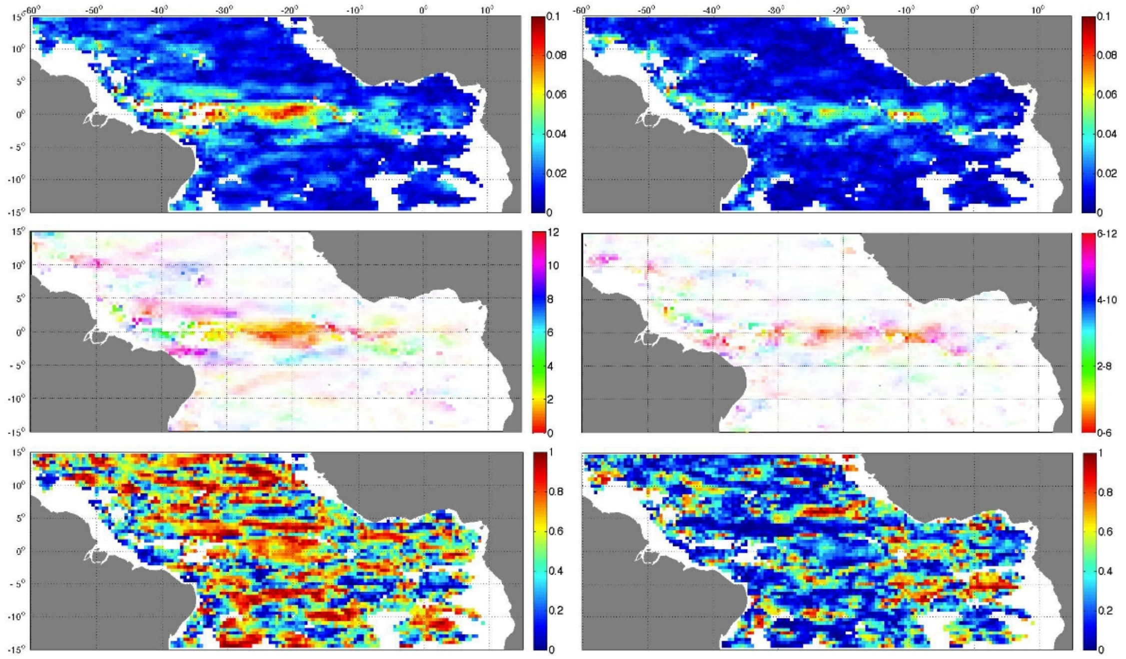

FIGURE 2 – (TOP PANELS) AMPLITUDE (MS-1) AND (MIDDLE PANELS) PHASE (MONTHS) DISTRIBUTIONS FOR THE (LEFT PANELS) ANNUAL AND (RIGHT PANELS) SEMI-ANNUAL CONTRIBUTIONS TO THE ZONAL COMPONENT OF THE 1000-DBAR VELOCITY; A TRANSPARENCY MASK (QUADRATIC PROPORTION TO AMPLITUDE) HAS BEEN APPLIED TO THE PHASE DISTRIBUTIONS IN ORDER TO EMPHASIZE THOSE AREAS WITH HIGH AMPLITUDES. THE BOTTOM PANELS ILLUSTRATES THE FRACTION OF THE VARIANCE EXPLAINED BY EITHER CONTRIBUTION.

REFERENCES

- Alford, M.H., 2001. Internal swell generation: the spatial distribution of energy flux from the wind to mixed layer inertial motions. Journal of Physical Oceanography 31, 2359–2368.

- Arnault, S., 1987. Tropical Atlantic geostrophic currents and ship drifts. Journal of Geophysical Research C92, 5076–5088.

- Artamonov, Y.V., 2006. Seasonal variability of geostrophic currents in the Atlantic Ocean according to altimetry data. Physical Oceanography 16, 177–187.

- Brandt, P., Eden, C., 2005. Annual cycle and interannual variability of the mid-depth tropical Atlantic Ocean. Deep-Sea Research I 52, 199–219.

- Bunge, L., Provost, C., Lilly, J.M., D'Orgeville, M., Kartavtseff, A., Melice, J.-L., 2006. Variability of the horizontal velocity structure in the upper 1600 m of the water column on the equator at 10°W. Journal of Physical Oceanography 36, 1287– 1304.

- Carton, J.A., Katz, E.J., 1990. Estimates of the zonal slope and seasonal transport of the Atlantic north equatorial countercurrent. Journal of Geophysical Research 95, 3091–3100.

- Claret, M., Rodríguez, R., Pelegrí, J.L., 2012. Salinity intrusion and convective mixing in the Atlantic equatorial undercurrent. Science Marina 76S1, 117–129.

- Csanady, G.T., 2001. Air–Sea Interaction, Laws and Mechanisms. Cambridge University Press, Cambridge, 239pp.

- Didden, N., Schott, F., 1992. Seasonal variation in the western tropical Atlantic: surface circulation from Geosat altimetry and WOCE model results. Journal of Geophysical Research 97, 3529–3541.

- Eriksen, C.C., 1981. Deep currents and their interpretation as equatorial waves in the Western Pacific Ocean. Journal of Physical Oceanography 11, 48–70.

- Garzoli, S.L., Katz, E.J., 1983. The forced annual reversal of the Atlantic north equatorial countercurrent. Journal of Physical Oceanography 13, 2082–2090.

- Gouriou, Y., Bourlès, B., Mercier, H., Chuchla, R., 1999. Deep jets in the equatorial Atlantic Ocean. Journal of Geophysical Research 104, 21217–21226.

- Richardson, P.L., Fratantoni, D.M., 1999. Float trajectories in the deep western boundary current and deep equatorial jets of the tropical Atlantic. Deep-Sea Research II 46, 305–333.

- Schmid, C., Molinari, R.L., Garzoli, S.L., 2001. New observations of the intermediate depth circulation in the tropical Atlantic. Journal of Marine Research 59, 281– 312.

- Schott, F.A., Dengler, M., Brandt, P., Affler, K., Fischer, J., Bourlès, B., Gouriou, Y., Molinari, R.L., Rhein, M., 2003. The zonal currents and transports at 35°W in the tropical Atlantic. Geophysical Research Letters 30, 1349.

- Stramma, L., Schott, F., 1999. The mean flow field of the tropical Atlantic Ocean. Deep-Sea Research 46, 279–303.

- Thierry, V., Treguier, A.M., Mercier, H., 2004. Numerical study of the annual and semi-annual fluctuations in the deep equatorial Atlantic Ocean. Ocean Modelling 6, 1–30.